

**DISPLAY DEVICE WITH A BLACK-OPTIMIZING BISTABLE NEMATIC  
 SCREEN AND METHOD FOR THE DEFINITION OF SAID DEVICE  
 FIELD OF THE INVENTION**

This invention relates to the field of liquid crystal display devices and more  
 5 precisely the optical configuration of a bistable nematic display operating  
 according to an optical mode which optimizes the black state of this display.

**AIM OF THE INVENTION**

The aim of this invention is to obtain a bistable display with a very good-  
 quality black state, i.e. a display having in this state a very low optical  
 10 transmission, taking account of certain stresses likely to be imposed on the cell.

Generally, the optical mode for which the quality of the black is  
 preponderant is the transmissive mode, but the optical configurations calculated  
 here also make it possible to produce a screen operating according to a  
 transfective or reflective mode.

**15 STATE OF THE ART**

**Bistable liquid crystal display switching between two textures differing by  
 180°**

The type of bistable liquid crystal display considered in this invention is a  
 display which switches between two textures, that are stable without an applied  
 20 electric field (from whence its bistability), different from each other by an angle of  
 $\pi$ . For one of the textures, the angle  $\Phi_U$  formed by the liquid crystal molecule  
 directors on the two surfaces of the cell is of the order of 0 to  $\pm 20^\circ$ . The molecules  
 remain virtually parallel between themselves, and this texture will be called U.  
 The second texture T has a twist angle  $\Phi_T = \Phi_U \pm \pi$ . The molecules carry out, in  
 25 this

texture T, a rotation of approximately  $\pm 180^\circ$  ( $\pm 20^\circ$ ) between the two surfaces of the cell.

The nematic liquid crystal is chiralized so as to present a spontaneous pitch  $p_0$  close to four times the thickness  $d$  of the cell, in order to equalize the energies of the two textures. The ratio between the thickness  $d$  of the cell and the spontaneous pitch  $p_0$ , i.e.  $d/p_0$ , is therefore approximately equal to  $0.25 \pm 0.1$ , preferably  $0.25 \pm 0.005$ . Without an electric field, they are the states of minimal energy.

To date two displays using this principle have been described.

Document [1] describes a display which carries out switching between the two textures U and T by applying an electric field pulse of specific shape. This display is based on a break of the a zenithal anchoring of the liquid crystal molecule on one of the alignment surfaces (documents [2] and [3]), i.e. the molecule is raised by the electric field before falling back on one side or the other, thus allowing the two textures U and T to be obtained. In this case, the structure of the electrodes necessary for the application of the field is standard, identical to that used for the liquid crystal displays of TN or STN type. This display is generally called BiNem<sup>®</sup>.

Document [4] describes a display which also uses an anchoring break and a specific type of electrode (called "comb shaped electrodes"), making it possible to obtain a lateral component of the electric field, i.e. parallel with the substrate. Switching between the two textures is carried out in this case by an effect qualified by the author as azimuthal anchoring break (documents [5] and [6]).

The switching method is not essential to this invention. In fact whatever the switching mode (zenithal or azimuthal anchoring break), the textures of the liquid crystal molecules are the same, the switching taking place between two twisted textures, one texture with a low twist angle  $\Phi_U$  and called U, and the other texture  
 5 with a high twist angle  $\Phi_T = \Phi_U \pm \pi$  and called T. And the optical behaviour of the display depends only on the textures of the liquid crystal molecules.

### **Optical modes of such displays**

Figure 1, attached, shows diagrammatically a liquid crystal display of the type described previously, to which the present invention can be applied.

10 This display comprises:

- . an analyser polarizer 10 on the side of the observer,
- . two plates 20, 30 confining the nematic liquid crystal molecules separated by a distance d, and
- . a polarizer 40 arranged on the rear of the display, i.e. on the opposite side with  
 15 respect to the observer.

An orthonormalized reference  $x'$ ,  $y'$ ,  $z'$  is represented in Figure 1, the directions  $x'$  and  $y'$  of which define a plane perpendicular to the direction of propagation of the light rays and  $z'$  is parallel to this direction of propagation.

The nematic director of the molecules on the plate 20, (i.e. the anchoring  
 20 direction on this plate 20) is referenced 22. The nematic director on the plate 30 is referenced 32.

The anchorings on the plates 20 and 30 are adapted to allow switching of the nematic liquid crystal molecules between two respectively stable states U and T, which differ from one another by a twist of the order of  $\pi$ , by the application of  
 25 electrical signals applied to electrodes provided on the

plates 20 and 30 according to the known modalities described in the documents mentioned previously.

Such a cell is characterized by:

- its delay  $\Delta n d$ , which is a product of the difference of the indexes  $\Delta n$  of the liquid crystal and the thickness  $d$  of the cell,
- its twist  $\Phi$ ,
- the angles  $P$  and  $A$  formed respectively by the  $P$  input or rear polarizer 40 and the  $A$  output or analyzer polarizer 10 (analyser) with a fixed reference (which according to Figure 1 arbitrarily coincides with the  $x'$  axis).

10        The output polarizer 10, situated on the side of the observer is always of transmissive type. The optical mode is determined by the nature of the rear polarizer 40:

15        . In purely transmissive mode, the screen operates as a transparency, the optical architecture is: source - screen - observer. The polarizer 40 is of transmissive type.

20        . In transfective mode, the polarizer 40 is transfective, i.e. partially reflecting: part of the polarized light is transmitted, the other part is reflected. This allows the screen to operate either in transmissive mode when it is illuminated by a rear source, or in reflective mode using ambient light as a source of light when it is not back-lighted.

- In reflective mode, the polarizer 40 is of reflective type. The screen is then exclusively illuminated by the ambient light reflected by this polarizer 40.

25        Documents [4] and [6] calculate a transmissive optical mode for a precise wavelength making it possible to simultaneously obtain for this wavelength (for example 550 nm), an optical transmission  $T = 0$  for one of the two textures (black state) and an optical transmission  $T = 1$  for the other texture.

By calculation, the authors obtain several sets of values of the characteristics of the cell ( $\Delta nd$ ,  $\Phi$ ,  $P$  and  $A$ ). All of the values corresponding to the shortest optical delay  $\Delta nd$  are shown in Table 1, attached.

This calculation of the optimal values is carried out using the analytical form of the optical transmission of a liquid crystal cell as a function of the parameters  $\Delta nd$ ,  $\Phi$ ,  $P$  and  $A$ , given in numerous publications (documents [7] or [8] for example).

The formula given in document [8] is the following:

$$T(\phi, \lambda) = \cos^2(\alpha + \beta) - \cos^2 X \cos 2\alpha \cos 2\beta \left[ \frac{\phi}{X} \tan X - \tan 2\alpha \right] \left[ \frac{\phi}{X} \tan X + \tan 2\beta \right] \quad [1]$$

$$\text{with } X(\phi, \lambda) = \sqrt{\phi^2 + \left( \frac{\pi \Delta nd}{\lambda} \right)^2} \quad [2]$$

In this formula  $\alpha$  and  $\beta$  are the angles formed by the polarizer 40 and the analyser 10 respectively with the liquid crystal director 32, 22 respectively situated on the same side.

Let  $\Phi_P$  and  $\Phi_A$  be the angles formed by the directors 32 and 22 with the  $x'$  axis of the reference  $x'y'z'$ .

Then:  $P = \alpha + \Phi_P$  and  $A = \beta + \Phi_A$  (see Figure 1)

The value of the twist of the liquid crystal cell texture is obtained by doing the difference between the director 22 of the liquid crystal on one of the faces of the cell and the director 32 on the other face :  $\Phi = \Phi_A - \Phi_P$

Formula [1] can also be obtained as a function of  $A$  and  $P$  instead of  $\alpha$  and  $\beta$ . In order to simplify the notations we will take the liquid crystal director 32 on the polarizer 40 side along  $x'$  i.e.  $\Phi_P = 0$  and  $\Phi_A = \Phi$ , hence:

$$P = \alpha \text{ and } A = \beta + \Phi$$

The authors of documents [4] and [6] are researching, for a given wavelength, the conditions which annul the transmission, then for the twist increased by  $\pi$  the conditions which make it possible to obtain the maximal value of 1. The delay  $\Delta$ nd taken for the two calculations must of course be the same.

5 The respective transmissions of the white and black states thus obtained are given in Figure 2, attached, as a function of the wavelength.

The value of the normalized luminances of the black state and of the white state calculated over all of the visible spectrum, are also shown in Table 1 as well as the contrast CR ratio of the two luminances. These values make it possible to  
10 compare the configurations proposed according to the state of the art and those proposed within the scope of this invention.

The normalized luminances are calculated as follows:

$$L = \frac{\int T(\lambda) \bar{y}(\lambda) s(\lambda) d\lambda}{\int \bar{y}(\lambda) s(\lambda) d\lambda}$$

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with  $T(\lambda)$  the optical transmission of the liquid crystal cell,  $\bar{y}(\lambda)$  the sensitivity of the eye and  $s(\lambda)$  the spectrum of the illumination source, which is assumed to be constant and equal to 1 (so-called "flat" spectrum).

This mode of calculation is carried out based on the principle that

- 20 - points are sought which simultaneously verify the perfect black and the perfect white for the 2 textures differing by  $\pi$ , at a fixed wavelength, and  
- all the cell parameters are free.

### **DESCRIPTION OF THE INVENTION**

The inventors propose a different process which makes it possible to  
25 obtain for a cell  $[\Phi_U; \Phi_T]$ , an optical mode

possessing a very good black, and which take account of certain industrial constraints.

The inventors propose, more precisely, to apply this process to a real cell, i.e. taking account of a so-called "finite" azimuthal anchoring (i.e. not infinitely strong), for example on one of the alignment layers. In this case the two textures differ by an angle of slightly less than  $\pi$ .

This invention thus proposes a nematic liquid crystal display device presenting two stable states, without an electric field, that are obtained by anchoring break, characterized by the fact that it comprises two polarizers, the first polarizer being placed on the side of the observer, the other polarizer being placed on the opposite face of the liquid crystal cell, the orientation of the two polarizers being shifted by a value equal to the rotatory power of the cell  $\pm \pi/2$ , the rotatory power corresponding to the effect of the most twisted texture.

According to other advantageous characteristics of this invention:

- 15 . the optical delay  $\Delta n d$  is of the order of  $240 \pm 80$  nm,
- . the optical delay  $\Delta n d$  is of the order of  $210 \pm 50$  nm,
- . the orientation of the polarizer placed on the opposite side with respect to the observer, as referring to the nematic director on the associated face of the cell, is comprised within the range containing the sub-range  $\pm (20^\circ \text{ to } 70^\circ)$  whilst the
- 20 orientation of the polarizer placed on the side of the observer, as referring to the same nematic director reference, is comprised within the range comprising the sub-range from  $\pm (20^\circ \text{ to } 70^\circ)$ ,
- . for a levo-rotatory liquid crystal, the orientation of the polarizer placed on the opposite side with respect to the observer is comprised within the range
- 25 comprising the sub-ranges  $-70^\circ \text{ to } -40^\circ$  and  $20^\circ \text{ to } 55^\circ$  whilst the orientation of the polarizer placed on the side of the observer is comprised

- within the range comprising the sub-ranges  $-55^{\circ}$  to  $-20^{\circ}$  and  $35^{\circ}$  to  $70^{\circ}$ , and for a dextro-rotatory liquid crystal, the orientation of the polarizer placed on the opposite side with respect to the observer is comprised within the range comprising the sub-ranges  $-55^{\circ}$  to  $-20^{\circ}$  and  $40^{\circ}$  to  $70^{\circ}$  whilst the orientation of the
- 5 polarizer placed on the side of the observer is comprised within the range comprising the sub-ranges  $-70^{\circ}$  to  $-35^{\circ}$  and  $20^{\circ}$  to  $55^{\circ}$ ,
- . the twist angle of the molecules in one of the two stable states is comprised between  $0^{\circ}$  and  $15^{\circ}$ ,
- . the twist angle of the molecules in one of the two stable states is comprised
- 10 between  $0^{\circ}$  and  $15^{\circ}$ , the optical delay  $\Delta n d = 200 \pm 40$  nm and for a levo-rotatory liquid crystal, the orientation of the polarizer on the opposite side with respect to the observer is comprised within the range  $[-60^{\circ}; -40^{\circ}] \cup [30^{\circ}; 50^{\circ}]$ , whilst the orientation of the polarizer on the side of the observer is comprised within the range  $[-50^{\circ}; -25^{\circ}] \cup [40^{\circ}; 70^{\circ}]$ ,
- 15 . the twist angle of the molecules in one of the two stable states is comprised between  $0^{\circ}$  and  $15^{\circ}$ , the optical delay  $\Delta n d = 200 \pm 40$  nm and for a dextro-rotatory liquid crystal, the orientation of the polarizer on the opposite side with respect to the observer is comprised within the range  $[-50^{\circ}; -30^{\circ}] \cup [40^{\circ}; 60^{\circ}]$ , whilst the orientation of the polarizer on the side of the observer is comprised
- 20 within the range  $[-70^{\circ}; -40^{\circ}] \cup [25^{\circ}; 50^{\circ}]$ ,
- . the twist angle of the molecules in one of the two stable states is comprised between  $0^{\circ}$  and  $15^{\circ}$ , the optical delay  $\Delta n d = 280 \pm 40$  nm and for a levo-rotatory liquid crystal, the orientation of the polarizer on the opposite side with respect to the observer is comprised within the range  $[-65^{\circ}; -45^{\circ}] \cup [25^{\circ}; 50^{\circ}]$ , whilst the
- 25 orientation of the polarizer on the side of the observer is comprised within the range  $[-50^{\circ}; -20^{\circ}] \cup [40^{\circ}; 70^{\circ}]$ ,



- . the twist angle of the molecules in one of the two stable states is comprised between  $0^\circ$  and  $15^\circ$ , the optical delay  $\Delta n d = 280 \pm 40$  nm and for a dextro-rotatory liquid crystal, the orientation of the polarizer on the opposite side with respect to the observer is comprised within the range  $[-50^\circ; -25^\circ] \cup [45^\circ; 65^\circ]$ , whilst the orientation of the polarizer on the side of the observer is comprised within the range  $[-70^\circ; -40^\circ] \cup [20^\circ; 50^\circ]$ ,
- . the angle formed by the brushing directions between themselves is comprised between  $10^\circ$  and  $15^\circ$ , the optical delay  $\Delta n d = 200 \pm 40$  nm and for a levo-rotatory liquid crystal, the orientation of the polarizer on the opposite side with respect to the observer is comprised within the range  $[-55^\circ; -35^\circ] \cup [35^\circ; 55^\circ]$ , preferentially  $[-40^\circ; -50^\circ] \cup [40^\circ; 50^\circ]$ , whilst the orientation of the polarizer on the side of the observer is comprised within the range  $[-45^\circ; -25^\circ] \cup [45^\circ; 70^\circ]$ , preferentially  $[-45^\circ; -25^\circ] \cup [50^\circ; 65^\circ]$ ,
- . the angle formed by the brushing directions between themselves is comprised between  $10^\circ$  and  $15^\circ$ , the optical delay  $\Delta n d = 200 \pm 40$  nm and for a dextro-rotatory liquid crystal, the orientation of the polarizer on the opposite side with respect to the observer is comprised within the range  $[-35^\circ; -55^\circ] \cup [35^\circ; 55^\circ]$ , preferentially  $[-40^\circ; -50^\circ] \cup [40^\circ; 50^\circ]$ , whilst the orientation of the polarizer on the side of the observer is comprised within the range  $[-70^\circ; -45^\circ] \cup [25^\circ; 45^\circ]$ , preferentially  $[-65^\circ; -50^\circ] \cup [25^\circ; 45^\circ]$ ,
- . the angle formed by the brushing directions between themselves is comprised between  $0^\circ$  and  $10^\circ$ , the optical delay  $\Delta n d = 200 \pm 40$  nm and for a levo-rotatory liquid crystal, the orientation of the polarizer on the opposite side with respect to the observer is comprised within the range  $[-65^\circ; -40^\circ] \cup [25^\circ; 50^\circ]$ , preferentially  $[-60^\circ; -45^\circ] \cup [30^\circ; 45^\circ]$ , whilst the orientation of the polarizer on the side of the observer is comprised within the

range  $[-55^\circ; -25^\circ] \cup [35^\circ; 65^\circ]$ , preferentially  $[-50^\circ; -30^\circ] \cup [40^\circ; 60^\circ]$ ,

. the angle formed by the brushing directions between themselves is comprised between  $0^\circ$  and  $10^\circ$ , the optical delay  $\Delta n d = 200 \pm 40$  nm and for a dextro-rotatory liquid crystal, the orientation of the polarizer on the opposite side with respect to the observer is comprised within the range  $[-50^\circ; -25^\circ] \cup [40^\circ; 65^\circ]$ , preferentially  $[-45^\circ; -30^\circ] \cup [45^\circ; 60^\circ]$ , whilst the orientation of the polarizer on the side of the observer is comprised within the range  $[-65^\circ; -35^\circ] \cup [25^\circ; 55^\circ]$ , preferentially  $[-60^\circ; -40^\circ] \cup [30^\circ; 50^\circ]$ ,

. the angle formed by the brushing directions between themselves is comprised between  $0^\circ$  and  $5^\circ$ , the optical delay  $\Delta n d = 280 \pm 40$  nm and for a levo-rotatory liquid crystal, the orientation of the polarizer on the opposite side with respect to the observer is comprised within the range  $[-70^\circ; -45^\circ] \cup [20^\circ; 45^\circ]$ , preferentially  $[-65^\circ; -50^\circ] \cup [25^\circ; 40^\circ]$ , whilst the orientation of the polarizer on the side of the observer is comprised within the range  $[-50^\circ; -25^\circ] \cup [40^\circ; 65^\circ]$ , preferentially  $[-45^\circ; -30^\circ] \cup [45^\circ; 60^\circ]$ ,

. the angle formed by the brushing directions between themselves is comprised between  $0^\circ$  and  $5^\circ$ , the optical delay  $\Delta n d = 280 \pm 40$  nm and for a dextro-rotatory liquid crystal, the orientation of the polarizer on the opposite side with respect to the observer is comprised within the range  $[-45^\circ; -20^\circ] \cup [45^\circ; 70^\circ]$ , preferentially  $[-40^\circ; -25^\circ] \cup [50^\circ; 65^\circ]$ , whilst the orientation of the polarizer on the side of the observer is comprised within the range  $[-65^\circ; -40^\circ] \cup [25^\circ; 50^\circ]$ , preferentially  $[-60^\circ; -45^\circ] \cup [30^\circ; 45^\circ]$ .

This invention also proposes a method for the optimization of the orientation of two polarizers in a nematic liquid crystal display device presenting two stable states by anchoring break, characterized by the fact that it

comprises the steps consisting of calculating the rotatory power of the cell and positioning the two polarizers, the first polarizer being placed on the side of the observer, the other polarizer being placed on the opposite face of the liquid crystal cell, according to an orientation shifted by a value equal to the rotatory power of the cell  $\pm \pi/2$ , the rotatory power corresponding to the effect of the most twisted texture.

According to other advantageous characteristics of the process of this invention:

. the rotatory power PR is calculated on the basis of the relationship:

10

$$PR \equiv \phi - \arctg\left(\frac{\phi}{X} \operatorname{tg} X\right) \quad [3]$$

$$\text{with } X(\phi, \lambda) = \sqrt{\phi^2 + \left(\frac{\pi \Delta n d}{\lambda}\right)^2} \quad [2]$$

. the process comprises the steps consisting of:

- 15 - calculating the rotatory power PR using a formula which utilizes the optical delay  $\Delta n d$ , the twist  $\Phi$  and the wavelength  $\lambda$ ,
- fixing the orientation A of the output polarizer (10) equal to  $P + PR \pm \pi/2$ , P representing the orientation of the polarizer (40) on the opposite side with respect to the observer and PR the rotatory power,
- 20 - researching the values of P which produce the highest resultant transmission value for the twist value of the order of  $\Phi \pm \pi$  and
- deducing A from it.
- . the transmission value is defined by the relationship:

$$25 \quad T_{as}(\phi, \lambda) = \cos^2(\alpha + \beta) - \cos^2 X \cos 2\alpha \cos 2\beta \left[ \frac{\phi}{X} \tan X - \tan 2\alpha \right] \left[ \frac{\phi}{X} \tan X + \tan 2\beta \right] \quad [1].$$

. the rotatory power PR is calculated on the basis of an optimal twist value  $\Phi_{opt}$  determined on the basis of the relationship:

$$\phi_{\text{ord}} = \pi \sqrt{1 - \left( \frac{\Delta n d}{\lambda_0} \right)^2} \quad [6]$$

- . the rotatory power PR is calculated on the basis of a twist value imposed by the azimuthal anchoring.
- . the method comprises a step of adaptation of the angles of the polarizers in order to improve the colorimetric neutrality of the white obtained.
- . the rotatory power PR is calculated on the basis of a twist value which integrates an uncoupling (DE) resulting from a finite azimuthal anchoring.
- Other characteristics, aims and advantages of this invention will become apparent on reading the detailed description which follows, and with reference to the attached drawings, given as non-limitative examples and in which:
- Figure 1 diagrammatically represents a liquid crystal cell applicable to this invention and defines the angles used in the rest of the description,
  - Figure 2 represents the respective transmissions for white (Figure 2a) and black (figure 2b) states obtained using a device according to the present invention, as a function of the wavelength,
  - Figure 3 diagrammatically represents the angles  $\psi$  and  $w$  characteristic of an elliptical polarization,
  - Figure 4 represents the rotatory power as a function of the optical delay for a free parameter  $\Phi$ ,
  - Figure 5 represents the optical transmission of the configuration ( $\Delta n d = 193 \text{ nm}$ ) described in Table 2 as a function of the wavelength, respectively for the white state in Figure 5a and for the black state in Figure 5b,

- Figure 6 diagrammatically represents the brushing directions on the analyser and polarizer side and the orientations of the liquid crystal molecules on the alignment layers for the case of an infinitely strong azimuthal anchoring,
- 5 - Figure 7 represents the rotatory power as a function of the optical delay for an imposed parameter  $\Phi$ ,
- Figure 8 represents the optical transmission of the configuration ( $\Delta n d = 275$  mm,  $\Phi$  imposed at  $\Phi_u = 0^\circ$  and  $\Phi_T = -180^\circ$ ) described in Table 3 as a function of  $\alpha$ ,
- Figure 9 represents the optical transmission of the configuration ( $\Delta n d = 275$  mm,
- 10  $\Phi$  imposed at  $\Phi_u = 0^\circ$  and  $\Phi_T = -180^\circ$ ) described in Table 3 as a function of the wavelength, respectively for the white state in Figure 9a and for the black state in figure 9b,
- Figure 10 represents the optical transmission of the configuration ( $\Delta n d = 193$  mm,  $\Phi$  imposed at  $\Phi_u = 0^\circ$  and  $\Phi_T = -180^\circ$ ) described in Table 3 as a function of
- 15 the wavelength, respectively for the white state in Figure 10a and for the black state in figure 10b,
- Figure 11 diagrammatically represents a similar view to Figure 3 for the case of a finite azimuthal anchoring on the plate of the cell situated on the side of the analyser.

20 The optimization calculations are carried out hereafter for the transmissive mode. However, this invention is directly applicable to the production of transfective or reflective screens, the only difference being the nature of the rear polarizer 40, all else being equal.

## 25 **CALCULATION PROCESS FOR THE OPTIMIZATION OF THE TRANSMISSIVE MODE OF A CELL [ $\Phi_u$ ; $\Phi_T$ ]**

Firstly, what characterizes the performance of a transmissive mode is the quality of its black. The optimization of the black state

must therefore be carried out not only over a single wavelength but over the whole of the visible spectrum. The condition  $T = 1$  for the white state at a fixed wavelength is not necessary, the screen being illuminated by a rear source, a  
 5 loss on the white state is acceptable, provided that it is not too great.

The process followed by the inventors consists of calculating the optimum mode producing the best black for several delay values  $\Delta n$ . The delay value finally chosen will depend on the desired compromise between the quality of the black and the quality of the white.

10 The texture T is more optically stable than the texture U, it is therefore chosen by the inventors in order to obtain the black.

#### **Characteristics of the polarization after passing through the liquid crystal layer**

The inventors use the Poincaré formalism, which describes the different  
 15 possible polarization states as well as the evolution of the polarization during its propagation in the cell by a plot on a sphere called a Poincaré sphere (see documents [9] or [10]).

This very powerful tool for those who can visualize in three-dimensional space allows a better comprehension of the optical effect of the liquid crystal cell  
 20 for the highly twisted texture (twist of the order of  $\pi$ ) which is used for the black in the transmissive mode.

The principal result obtained thanks to this tool is that the texture T (twist  $\Phi_T$  of the order of  $\pi$ ) is, for cell delays  $\Delta n$  less than or equal to  $\lambda/2$  ( $\lambda$  representing a wavelength of the visible spectrum), equivalent to a virtually perfect rotatory  
 25 power PR. This signifies that whatever the input polarization angle P, the output polarization Pout is

weakly elliptical (nearly linear) and the major axis of this ellipse forms an angle PR with respect to P.

The output polarization Pout, which is a priori any polarization and thus elliptical, can be characterized by 2 angles  $\psi$  and  $\omega$ .  $\psi$  is the angle formed by the major axis of the ellipse with x' and  $\omega$  characterizes the ellipticity of the polarization as illustrated in Figure 3.

We have  $\psi = P + PR$

Thanks to the Poincaré sphere it is also possible to obtain the analytical form of PR (approximate value) and  $\omega$ .

$$10 \quad PR \cong \phi - \arctg\left(\frac{\phi}{X} \operatorname{tg} X\right) \quad [3]$$

$$\sin 2\omega = 2 \sin\eta \sin X (\cos 2\alpha \cos\eta \sin X + \sin 2\alpha \cos X) \quad [4]$$

$$\text{with } \cos\eta = \frac{\phi}{X}.$$

Formula [3] is valid as a first approximation, when X is close to  $\pi$ , which is always true in the cases dealt with within the scope of this invention.

Annulation of the ellipticity  $\omega$  is equivalent to obtaining at the cell output a linear polarization, i.e. a configuration where a perfect black or a white can be obtained with the analyser.

The fact that formula [3] makes it possible to predict the value of the rotatory power makes it possible to calculate the angle  $\psi$  of the output polarization Pout. The configuration A for the analyser 10 producing the best black for a given orientation P of the polarizer 40 is A perpendicular to  $\psi$ .

$$\text{i.e. } A = P + PR \pm \pi/2 \quad [5]$$

The condition which annuls the ellipticity  $\omega$  is

$X = \pi$ . i.e.:

$$\phi_{opt} = \pi \sqrt{1 - \left( \frac{\Delta nd}{\lambda_0} \right)^2} \quad [6]$$

5

Thus when  $X$  is fixed, there exists a relationship between  $\Phi$  and  $\Delta nd$  making it possible to obtain a linear output polarization  $P_{out}$ , which guarantees the obtaining of a perfect black at a given  $\lambda$ , with the analyser 10 perpendicular to the output polarization. The value of  $\Phi$  calculated with formula [6] for a given delay  $\Delta nd$  will be called  $\Phi_{opt}$ .

10

The optimal configuration is calculated for a cell delay  $\Delta nd$  and a given wavelength  $\lambda$ .

The procedure for calculating the best configuration within the scope of this invention is preferably the following:

#### 15 **Case where the parameter $\Phi$ is free**

Formula [6] makes it possible to calculate the optimal  $\Phi$  value,  $\Phi_{opt}$ , for the chosen delay.

#### Optimization of the black

From the fixed values of  $\Delta nd$  and  $\lambda_0$  ( $\lambda_0$  being a chosen wavelength in the visible spectrum, for example 550 nm),  $\Phi_T = \Phi_{opt}$  is determined from formula [6], then the exact value of the rotatory power  $PR$  is calculated with formula [3]. The value of the rotatory power  $PR$  as a function of the cell delay is given in Figure 4. It is noted that for a delay of between 190 nm and 320 nm,  $PR$  varies between 10° and 35°.

25 In order to obtain a black, an orientation  $A$  of the analyser 10 perpendicular to the output polarization  $P_{out}$  (Formula[5]) is required:

$$\text{i.e. } A = P + PR \pm \pi/2$$



### Investigation of the best white

A (or  $\beta$ ) is replaced by its value as a function of P (or  $\alpha$ ) in the transmission formula as in formula [1], with  $\Phi_U = \Phi_T + \pi$ . The only remaining variable is P (or  $\alpha$ ). The value of P (or  $\alpha$ ) is sought which produces the highest value of T. Once

5 P is determined, the value of A is obtained using formula [5].

### **Calculation example - Improvement of the black state.**

Starting with these considerations, it appears that a reduction in the delay  $\Delta n d$  of the cell with respect to the value recommended by the prior art makes it possible to improve very clearly the quality of the black, the price to be paid being

10 a loss with respect to the passing-state (white).

Table 2, attached, shows several theoretical sets of parameters of the cell optimized in order to obtain the best black on the visible spectrum, and calculated according to the process described previously.

For the case  $\Delta n d = 193$  nm, it is seen that the contrast has been multiplied  
15 by 3 with respect to the conventional solution of Table 1 (state of the art), at the cost of a loss of 20% with respect to the white state.

The respective transmissions of the white and black states obtained for the case  $\Delta n d = 193$  nm described in Table 2 are given in Figure 5 as a function of the wavelength. The spectrum of the black is very much improved in the blue, at the  
20 cost of a less "flat" white state which will be slightly bluish.

However, the values given in Table 2 correspond to theoretical values. In practice the industrial manufacturing processes of liquid crystal cells impose constraints on the real anchorings and twist which must be taken into account.

### Taking account of the constraint $\Phi$ imposed

In the practical case of an infinitely strong azimuthal anchoring the director 22, 32 on each face 20, 30 of the cell is determined by the brushing direction of the alignment layer (for example of polyimide chemical type) used on this face.

- 5 Actually, for an infinitely strong azimuthal anchoring the director of the liquid crystal aligns parallel to the brushing direction (see Figure 6). In this case, a precise value of  $\Phi$  is obtained by fixing the brushing directions of the two alignment layers on the production machine of the display, so that they form an angle  $\Phi$  between themselves.
- 10 As regards questions of mounting convenience or satisfactory operation of the cell, the angles of the brushing directions of the cell can be imposed, which therefore imposes  $\Phi_U$  and  $\Phi_T$ . In this case, the calculation of the best configuration for P and A according to the criterion: "best black without too many losses with respect to the white", is not easy with an analytical formula such as [1].
- 15 The process proposed by the inventors makes it possible to carry out the calculation more easily.

- 20 The rotatory power is calculated for the value of  $\Phi_T$  imposed, then as previously the value of A as a function of P following from formula [5] is introduced into formula [1] for  $\Phi_U$  imposed, and the values of P which maximize the transmission are sought.

### Examples of calculation with $\Phi$ imposed

The following are taken as examples:  $\Phi_T = -\pi$  i.e.  $\Phi_U = 0^\circ$  (antiparallel brushing directions) and  $\lambda = 550$  nm.

In this case,  $\alpha = P$  and  $\beta = A$ .

- 25 The calculated value of the rotatory power as a function of the cell delay is given in Figure 7. By comparison with Figure 4

where  $\Phi$  is optimal, it is seen that PR essentially depends in first approximation on the delay, and also on the value of  $\Phi$ .

Example 1:  $\Delta n d = 275$  nm

It is calculated that  $PR = 19.2^\circ$  and ,  $\beta = \alpha + PR \pm \pi/2$ .

5 The transmission T calculated for  $\Phi_U = 0^\circ$  is given in Figure 8.

The values of  $\alpha$  which give the maximal value of T are (see Figure 8):

$$\alpha = -54^\circ \text{ hence } \beta = 55^\circ$$

$$\alpha = 36^\circ \text{ hence } \beta = -35^\circ$$

These two configurations are equivalent.

10 The optical transmissions of the white and black states are given in Figure 9. The performances of this configuration are given in Table 3.

Example 2:  $\Delta n d = 193$  nm

In the same manner as for example 1, it is calculated:

$$PR = 10.17^\circ$$

15  $\alpha = -50^\circ \text{ hence } \beta = 55^\circ$

$$\alpha = 40^\circ \text{ hence } \beta = -40^\circ.$$

The optical transmissions of the white and black states are given in Figure 10. The performances of this configuration are given in Table 3.

20 For these two delay cases, the same tendencies are found for  $\Phi$  imposed, as for  $\Phi$  free: a better black for 193 nm at the cost of a less luminous and less "flat" white.

**REAL CASE OF A FINITE AZIMUTHAL ANCHORING**

25 When the azimuthal anchoring is finite (not infinitely strong), the elastic forces which act on the molecules close to the surface due to the chiral doping of the liquid crystal mixture, make these molecules "uncouple", i.e. the director of the liquid crystal is no longer strictly parallel to the brushing direction,

but shifted by an angle DE called “elastic uncoupling”. In order to simplify the illustration, it is assumed that a single anchoring layer has a finite azimuthal anchoring, the other layer having an infinitely strong azimuthal anchoring. The uncoupling moves in the direction of reducing the absolute value of the twist of low value  $\Phi_U$ , which becomes, for example,  $\Phi_U - DE$  for  $\Phi_U > 0$ , and of reducing the absolute value of the twist of high value  $\Phi_T$ , which becomes, for example,  $\Phi_T + DE$  for  $\Phi_T < 0$  (see Figure 11).

The angle formed by the brushing directions between themselves is called  $\Phi^*$ .

Due to the uncoupling we have:

$$\Phi_T - \Phi_U = -\pi + 2.DE$$

The elastic uncoupling is directly connected to the azimuthal anchoring force characterized by its extrapolation length  $L_{az}$  according to the relationship:

$$DE = \frac{\pi.L_{az}}{2d}$$

A finite azimuthal anchoring typically has a  $L_{az}$  of the order of 100 to 200 nm, i.e. DE comprised between a few degrees and approximately 15°. The parameter DE is a physical parameter which can be measured experimentally, and therefore assumed to be known.

The inventors have chosen for the following examples values of DE of 5° and 10°.

#### **Case where the parameter $\Phi^*$ is free**

The optimal values of  $\Phi^*$  will now be calculated as a function of the uncoupling DE, as well as the corresponding optical configuration.

For each delay  $\Delta$  and the optimal value of the high twist as defined by the formula [6] is called  $\Phi_{opt}$ .

The effective value of the high twist  $\Phi_T$  is (cf Figure 11):

$$\Phi_T = -\pi + \Phi^* + DE$$

One wants  $\Phi_T = \Phi_{opt}$  hence

$$\Phi^* = \pi + \Phi_{opt} - DE$$

- 5        The rotatory power is calculated for  $(\Delta nd, \Phi_{opt})$ , then the relationship between A and P is introduced into the formula [1] for  $\Phi_U = \Phi^* - DE$ , and the values of P which maximize the transmission are sought graphically.

Example of calculation with  $\Delta nd = 193$  nm

- 10        The value of  $\Phi_{opt}$  is in this case  $-168.5^\circ$ , corresponding to a rotatory power of  $11.5^\circ$ .

The calculations and performances of the optimized configuration corresponding to each uncoupling value are given in Table 4.

- 15        Performances are found which are close to those of Table 2, which is to be expected as, in both cases, it is possible to configure the cell such that  $\Phi_T$  is equal to  $\Phi$  optimum, which guarantees a good black.

Example of calculation with  $\Delta nd = 275$  nm

The value of  $\Phi_{opt}$  is in this case  $-156^\circ$ , corresponding to a rotatory power of  $24^\circ$ .

- 20        The calculations and performances of the optimized configuration corresponding to each uncoupling value are given in Table 5.

Because of the higher delay, the contrast is less good, but it retains a correct value ( $>200$ ) as it is possible to configure the cell so that  $\Phi_T$  is equal to  $\Phi$  optimum.

### Case where the parameter $\Phi^*$ is imposed

The brushing direction of the cells  $\Phi^*$  can be imposed, for example by the industrial process.

The effective value of  $\Phi_T$  in this case is (cf Figure 11):

$$5 \quad \Phi_T = -\pi + \Phi^* + DE$$

The rotatory power is calculated for the corresponding value of  $\Phi_T$ , then, as previously, the value of A as a function of P resulting from formula [5] is introduced into formula [1] for  $\Phi_U = \Phi^* - DE$  and the values of P which maximize the transmission are sought. The results for the delay values 193 nm and 275 nm are given in Tables 6 and 7 for the case  $\Phi^*$  imposed equal to  $0^\circ$ .

The effect of elastic uncoupling diminishes the value of the twist of high value  $\Phi_T$ , which brings  $\Phi_T$  closer to the value  $\Phi_{opt}$  ( $-168.5^\circ$  for the case 193 nm and  $-156^\circ$  for 275 nm). The contrast therefore improves when the uncoupling increases. For 193 nm and  $DE = 10^\circ$ , it is almost  $\Phi_{opt}$ , and the contrast value obtained, 896, is therefore very close to the value obtained with  $\Phi_{opt}$  (916).

### VARIANTS OF THE INVENTION

The configurations calculated for the transmissive mode are applicable to the transflective or reflective modes. The angles calculated are identical, only the nature of the polarizer 40 on the source side P differs according to the mode.

20 These modes favour the black, and thus have a non-optimized white in terms of brilliance.

In order to slightly modify the colorimetry of the white, the positions of the polarizers 40 and 10 can be adjusted in the vicinity of their calculated position, on condition that the relationship between them (given by the rotatory power) which guarantees the best black is respected.

The rotatory power PR is function of the twist  $\Phi$  (close to  $\pi$ ) and the cell delay. The angles between P and A which depend on the value of PR are therefore to a large extent dependent on the delay value of the cell.

$\Phi_U$	$\Phi_T = \Phi_U - \pi$	$\Delta nd$	P	A	Lblack $\Phi_T = \Phi_U - \pi$	Lwhite $\Phi_U$	CR
22.5°	-157.5°	266 nm	-45° 45°	+67.5° -22.5°	0.0031	0.988	317

5 Table 1: transmissive optical mode of a cell [ $\Phi$ ;  $\Phi - \pi$ ] according to the state of the art (Document [4] US 2003/0076455)

$\Delta nd$	$\Phi_U$	$\Phi_T = \Phi_U - \pi$ opt	P	A	Lblack $\Phi_T = \Phi_U - \pi$	Lwhite $\Phi_U$	CR
220 nm	15°	-165°	-45° 45°	60° -30°	0.0015	0.90	623
193 nm	11.5°	-168.5°	-45° 45°	56.5° -33.5°	0.00087	0.8	916

Table 2: example of solutions allowing an improvement of the black state

$\Delta nd$	$\Phi_U$	$\Phi_T = \Phi_U - \pi$ imposed	P	A	Lblack $\Phi_T = \Phi_U - \pi$	Lwhite $\Phi_U$	CR
275 nm	0°	-180°	-54° 36°	55° -35°	0.028	0.987	35
193 nm	0°	-180°	-50° 40°	50° -40°	0.0044	0.787	178

10 Table 3: examples of solutions optimizing the black state with a twist imposed at  $-\pi$

DE	$\Phi^*$	$\Phi_U$	P	A	Lblack $\Phi_T$	Lwhite $\Phi_U$	CR
5°	6.5°	1.5°	-50°	52.5°	0.00087	0.80	918
			40°	-38.5°			
10°	1.5°	-3.5°	-52°	49.5°	0.00086	0.79	919
			38°	-40.5°			

Table 4: example of solutions for different elastic uncoupling values for ( $\Delta n_d = 193$  nm;  $\Phi_{opt} = -168.5^\circ$ ;  $\lambda = 550$  nm)

5

DE	$\Phi^*$	$\Phi_U$	P	A	Lblack $\Phi_T$	Lwhite $\Phi_U$	CR
5°	19°	14°	-51°	63°	0.0035	0.984	282
			40°	-25°			
10°	14°	9°	-52°	62°	0.0034	0.986	285
			38°	-28°			

Table 5: example of solutions for different elastic uncoupling values for ( $\Delta n_d = 275$  nm;  $\Phi_{opt} = -156^\circ$ ;  $\lambda = 550$  nm)

DE	$\Phi^*$	$\Phi_U$	P	A	Lblack $\Phi_T$	Lwhite $\Phi_U$	CR
5°	0°	-5°	-52°	48.5°	0.0020	0.789	399
			38°	-41.5°			
10°	0°	-10°	-55.5°	45.5°	0.0009	0.781	896
			34.5°	-44.5°			

Table 6: example of solutions for different elastic uncoupling values for ( $\Delta n_d = 193$  nm;  $\lambda = 550$  nm) with  $\Phi^*$  imposed at  $0^\circ$ .

DE	$\Phi^*$	$\Phi_U$	P	A	Lblack $\Phi_T$	Lwhite $\Phi_U$	CR
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5°	0°	-5°	-56.5° 33.5°	53.5° -36.5°	0.019	0.99	51
10°	0°	-10°	-60.5° 29.5°	50.5° -39.5°	0.011	0.99	87

Table 7: example of solutions for different elastic uncoupling values for ( $\Delta n d = 275$  nm;  $\lambda = 550$  nm) with  $\Phi^*$  imposed at  $0^\circ$ .

The values given in the above tables correspond to a levo-rotatory texture.

- 5 The invention is of course valid when the liquid crystal is dextro-rotatory. Such a dextro-rotatory texture reverses the respective signs of  $\Phi_U$  and  $\Phi_T$ , and of the rotatory power PR.

10 In this case, the equivalent configurations are obtained by reversing the signs of  $\Phi_U$  and  $\Phi_T$  and PR. The optimal orientations of the polarizer 40 and analyser 10 are obtained by reversing the signs of the P's and the A's. By way of example, the dextro-rotatory values corresponding to Tables 5, 6 and 7 of the levo-rotatory case are given below, in Tables 8, 9 and 10 respectively:

DE	$\Phi^*$	$\Phi_U$	P	A	Lblack $\Phi_T$	Lwhite $\Phi_U$	CR
5°	-19°	-14°	51° -40°	-63° 26°	0.0035	0.984	282
10°	-14°	-9°	52° -38°	-62° 28°	0.0034	0.986	285

15 Table 8: example of solutions for different elastic uncoupling values for ( $\Delta n d = 275$  nm;  $\Phi_{opt} = 156^\circ$ ;  $\lambda = 550$  nm) - case of a dextro-rotatory liquid crystal

DE	$\Phi^*$	$\Phi_U$	P	A	Lblack $\Phi_T$	Lwhite $\Phi_U$	CR
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5°	0°	5°	52° -38°	-48.5° 41.5°	0.0020	0.789	399
10°	0°	10°	55.5° -34.5°	-45.5° 44.5°	0.0009	0.781	896

Table 9: example of solutions for different elastic uncoupling values for ( $\Delta n d = 193$  nm;  $\lambda = 550$  nm) with  $\Phi^*$  imposed at 0°- case of a dextro-rotatory liquid crystal.

5

DE	$\Phi^*$	$\Phi_U$	P	A	Lblack $\Phi_T$	Lwhite $\Phi_U$	CR
5°	0°	5°	56.5° -33.5°	-53.5° 36.5°	0.019	0.99	51
10°	0°	10°	60.5° -29.5°	-50.5° 39.5°	0.011	0.99	87

Table 10: example of solutions for different elastic uncoupling values for ( $\Delta n d = 275$  nm;  $\lambda = 550$  nm) with  $\Phi^*$  imposed at 0°- case of a dextro-rotatory liquid crystal.

## REFERENCES

- 10 Document [1]: patent FR-A-2 740 894  
Document [2]: "Fast bistable nematic display using monostable surface anchoring switching" Proceeding SID 1997, p41-44  
Document [3]: "Recent improvements of bistable nematic displays switched by anchoring breaking" SPIE vol. 3015 (1997), p61-69
- 15 Document [4]: patent US 2003/0076455  
Document [5]: "Dynamic flow, broken surface anchoring, and switching bistability in three-terminal twisted nematic liquid crystal displays" Journal of Applied Physics, vol 90, no. 6, p 3121-3123 (2001)  
Document [6]: "Three terminal bistable twisted nematic liquid crystal displays",  
20 Applied Physics letters, vol 77, no. 23, p 3716-3718, December 2000

Document [7]: H.L. Ong "Origin and characteristics of the optical properties of general twisted nematic liquid crystal displays" J. Appl. Phys. 64, 614 (1988)

Document [8]: P. Yeh and C. Gu "Optics of liquid crystal displays", Wiley, New York, 1999

- 5 Document [9]: Poincare H., Théorie mathématique de la lumière, Gauthiers Villars (1889)

Document [10]: Schurcliff W.A. "Polarized light, production and use" Harvard University Press (1966)